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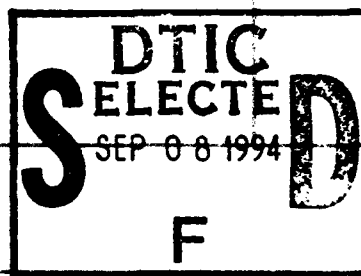
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The goal of our research is to build an ultrafast all-optical switching device. Such a device would be the first step towards ultrafast switching systems for the information highway and all-optical computing applications. Our work is motivated by the demonstration of an all-optical switch in a silica optical fiber. While this device displays all essential switching functions, the small material nonlinearity requires fibers of 1km lengths, resulting in long latency periods. because we have the ability to make polymer fibers with optical nonlinearities that are three orders of magnitude large, we can make sub-meter length devices. In our first year, we have worked out the preliminaries required to make such a device which includes optimization of the fiber drawing process, characterization of crucial material properties, and the design of optical switches that take advantage of the polymer fiber's nonlinearity. We have demonstrated the fabrication of fibers with cores that are less than 10um in diameter, have shown that these can support single mode light-guiding (required for optimum device operation), and have designed and build a Sagnac interferometer experiment that is being used to characterize material nonlinearity. This experiment will be eventuall converted to an all-optical switch

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Polymer Fibers for Nonlinear Optics

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June 1, 1994

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ANNUAL REPORT TO AFOSR

REPORT PERIOD: 01 May 93 - 30 Apr 94

ABSTRACT The goal of our research is to build an ultrafast all-optical switching device. Such a device would be the first step towards ultrafast switching systems for the information highway and all-optical computing applications. Our work is motivated by the demonstration of an all-optical switch in a silica optical fiber. While this device displays all essential switching functions, the small material nonlinearity requires fibers of 1km lengths, resulting in long latency periods. Because we have the ability to make polymer fibers with optical nonlinearities that are three orders of magnitude larger, we can make sub-meter length devices. In our first year, we have worked out the preliminaries required to make such a device which includes optimization of the fiber drawing process, characterization of crucial material properties, and the design of optical switches that take advantage of the polymer fiber's nonlinearity. We have demonstrated the fabrication of fibers with cores that are less than $10\mu\text{m}$ in diameter, have shown that these can support single mode light-guiding (required for optimum device operation), and have designed and built a Sagnac interferometer experiment that is being used to characterize material nonlinearity. This experiment will be eventually converted to an all-optical switch by replacing bulk components with fibers.

The project goal is to make an all-optical switch in a polymer optical fiber. The work we performed during the first year of the award centered on developing the experiments, materials processing, and characterization required to achieve the goal.

In summary, we have:

- Demonstrated single mode guiding in a nonlinear-optical core of a polymer fiber.
- Measured optical loss of fiber core material.
- Designed and built an apparatus to measure material nonlinearity. This will eventually be used to demonstrate all-optical switching.
- Evaluated the all-optical device figure of merit (both one- and two-photon) in our materials.

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A brief introduction to the motivation work and details of the above accomplishments are described below.

While silica glass fibers have been used to make an all-optical transistor, its one kilometer length prohibits widespread applications. Given the larger third-order response in doped polymers, we are applying our expertise in making single mode polymer optical fibers to making sub-meter-length Sagnac transistors. As a first step, we have built a bulk Sagnac interferometer with improved measurement sensitivity that will be used to characterize the nonlinear optical response in thin film samples and waveguides to ensure that the guided mode in the nonlinear fiber core possesses the expected nonlinearity.

In this experiment, the incident pulse train's envelope is modulated with a rotating half wave plate and polarizer. After the polarizing beam splitter, the two orthogonally counter propagating pulses travel through the sample and attenuator, are recombined at the same beam splitter and measured with a photodiode after interfering in the second polarizer. The pulse that passes through the sample before the absorber induces an intensity dependent phase shift while the second weaker pulse acts as a reference against which the phase-shifted pulse interferes. Because both pulses travel through the same path, the technique is able to measure an accurate intensity dependent refractive. By comparing the signal at the modulated frequency (provided by the rotating half wave plate) and at twice the modulated frequency, a determination of the third-order nonlinear-optical susceptibility is possible.

This apparatus is operational and is being applied to the measurement of known materials for the purpose of calibration. As this project evolves, the bulk components will be sequentially replaced with fibers to make the all-optical fiber-based transistor.

In parallel to the Sagnac interferometer $\chi^{(3)}$ characterization effort, we have been studying polymer processing conditions to improve the single mode guiding properties of a polymer optical fiber. Furthermore, we have concentrated on optical loss measurements in a fiber to investigate ways in which the figure of merit can be improved. Each of these efforts are briefly described below.

The single mode guiding properties of an ISQ-doped PMMA fiber was studied at a wavelength of $1.3\mu\text{m}$ using a microscopic imaging system. In these experiments, the light is launched into a single mode fiber core with a microscope objective. Both ends of the fiber are made smooth by bringing them in contact with a hot light bulb. On the coupling end, it is crucial that the $9\mu\text{m}$ diameter core be smooth to ensure that the mode can be excited. The output end of the fiber is imaged with a microscope objective and eyepiece onto an infra red camera array. An observation of the end of a light-guiding fiber shows a light intensity that is peaked at the center of the fiber and there are no nodes in the intensity - an indication of a single-mode guide.

An important device material property is the nonlinearity to loss figure of merit. We have investigated the loss of several dopant dye molecules in PMMA polymer using the cut-and-measure technique in which the intensity of light leaving a fiber is measured as a function of length by successively cutting off small pieces at the output end. We have found that the measured loss is reproducible in the same materials and in PMMA doped with different dyes. The value of the loss is about 0.3dB/cm in all samples. This number is consistent with those reported by Kaino for neat PMMA. Because the loss of the fiber is at present limited by the polymer host, our early proposal that the figure of merit can be improved by using more transparent polymer hosts is confirmed. Because the loss in PMMA in the near IR is known to arise from CH stretch overtones, we plan to study the possibility of using deuterated and fluorinated polymers to decrease the loss.

In contrast to the linear figure of merit, which is given by the nonlinearity to loss ratio, we have

also measured the spectrum of the imaginary part of the third-order nonlinear-optical response with quadratic electroabsorption spectroscopy and have used a Kramers-Kronig transformation to determine the real part. The ratio of the real to imaginary part of the third-order susceptibility defines the two-photon figure of merit. If this figure of merit is larger than about 2π , the material is adequate for interferometric-based all-optical devices. For materials in which the figure of merit is larger than 8π , a directional coupler all-optical device is possible. We have found that the figure of merit is acceptable for interferometric devices in the near IR while directional coupler devices will probably be possible further into the IR. All-optical third-order susceptibility determinations are in progress to assess the two-photon figure of merit around $1\mu m$.

PERSONNEL SUPPORTED:

Graduate Students:

- Dennis Garvey
- Qin Li

Undergraduate Students:

- Marc Dayton

Technicians:

- Phil Young

PAPERS AND PRESENTATIONS

- M. G. Kuzyk, "All-Optical Materials and Devices," in *Science and Technology of Organic Thin Films for Waveguiding Nonlinear Optics*, F. Kajzar and J. D. Swalen, eds. Gordon and Breach, in press. (invited)
- M. G. Kuzyk, Q. Li, D. J. Welker, S. Zhou, and C. W. Dirk, "All-Optical and Photomechanical Devices in Polymer Optical Fiber," SPIE OELASE'94 2143, (1994) (invited)
- M. G. Kuzyk, Q. Li, M. Lobel, D. J. Welker, P. Young, S. Zhou, and C. W. Dirk, "Intensity-Induced Phase Shift Phenomena in Polymer Optical Fibers," 4th IKETANI International Conference on Optically Nonlinear Organic Materials and Applications, Technical Digest, 153 (Hawaii, 1994) (invited)
- C. Poga, M. G. Kuzyk, S. Martinez, and C. W. Dirk, "Quadratic Electroabsorption Spectroscopy as a Probe of $\chi^{(3)}$ Mechanisms in Dye-Doped Polymers, SPIE Proc. 2025, 363 San Diego (1993).
- M. G. Kuzyk, Q. Li, D. J. Welker, S. Zhou, and C. W. Dirk "New Device Concepts in Polymer Optical Fibers," Joint ACS/OSA Symposium on Organic Thin Films for Photonic Applications, Toronto (1993) (invited).
- M. G. Kuzyk, Q. Li, D. J. Welker, S. Zhou, and C. W. Dirk, "Applying Third-Order Field Mechanisms to a New Class of Devices," Proceedings of the First International Conference on Organic Nonlinear Optics, p76, Val Thorens, France (1994) (invited)

INTERACTIONS

We have interacted with other researchers supported by AFOSR in areas of common interest. We have collaborated with Prof. Singer of Case Western Reserve University who has characterized the excited state character of our squaraine dyes (those used in fiber cores), and with Prof. Dirk of Univ, of Texas at El Paso, who has supplied chromophores and polymer processing information.

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